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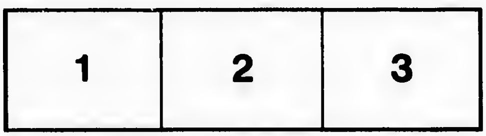

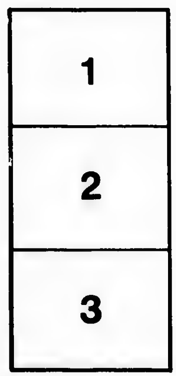

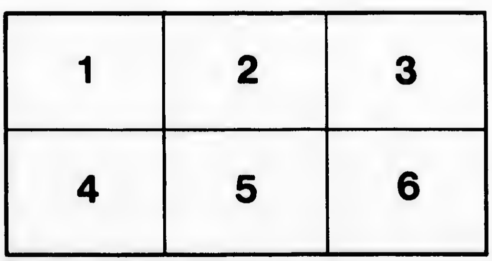

[TRANSACTIONS OF THE AM... OF MINING ENGINEERS.]

The Origin and Mode of Occurrence of the Lake Superior Copper-Deposits.

BY DR. M. E. WADSWORTH, PRESIDENT OF THE MICHIGAN COLLEGE OF MINES, HOUGHTON, MICHIGAN.

(Lake Superior Meeting, July, 1897.)

THE region about the south shore of Lake Superior is to geologists one of the most interesting districts of the United States, embracing as it does, in a limited area, old crystalline rocks, together with forms that are almost in their original condition of a beach sand and mud. In this region was first established the base of the geological column, the Azoic ("without life") System of Foster and Whitney, or the Archæan ("the beginning") of Dana. Overlying this system are found the sandstones and limestones of the Palæozoic ("ancient life"), and their associated lava-flows (Algonkian ?).

These systems possess a strong economic interest, owing to the stores of iron in the Azoic and of copper in the Palæozoic or Eozoic of this district, which forms one of the most important mining regions in America.

The geology of this section is so difficult and complicated that, in its general discussion, perhaps no proposition can be stated concerning any portion of it to which exceptions cannot be taken. Indeed, out of the general discussion of different points comes in time the truth, and various geologists, even now, are working over this region in the endeavor to arrive at some consensus, or at least to determine upon what points they can agree, and upon what points difference of opinion will have to exist between them at present, until further evidence can be obtained. The writer will endeavor to give in a brief form that which appears to him at present to be the most correct statement of the geological structure of the region, admitting that from time to time, as more complete evidence shall be obtained, he expects to change his views in the future, as he has done in the past, if that evidence shall cause him to believe that he has been mistaken.

The rocks south of Lake Superior have been formed in three ways: 1st, by mechanical means; 2d, by eruptive, igneous, or volcanic agencies; 3d, by chemical action.

Fragmental or Detrital Rocks.

The mechanical agencies of the Azoic time acted upon some prior-formed rocks in like manner as we see rain, winds, waves, frosts, etc., now breaking down the rocks of the present day, causing them to be deposited as soil, mud, sand and shingle, forming detrital or sedimentary deposits. Such detritus one can see upon the shores of any lake or sea, being in many localities variable in its composition, and oftentimes abruptly changing from fine mud to sand, or even to coarse shingle. At other localities upon the same lake shore one may observe a nearly uniform sand, mud or shingle stretching away as far as the eye can reach along that shore. Like uniformity and like abrupt changes are seen by the geologist in the rocks formed from the ancient muds, sands and shingle of the early seas and lakes. These deposits may have remained on the surface of the ancient beach, or may have been deeply buried under succeeding deposits; but whatever may have been their position relative to the earth's surface, they have been greatly changed or altered from their original condition, although the evidences of that original condition remain plainly visible to him who has learned to read the worn, torn and worm-eaten book of Nature. In truth it may be said that no event can take place without leaving its effects behind, and these can be interpreted with greater or less clearness until their record has been entirely obliterated.

To return: we find that these old muds, sands and shingle have been acted upon, and metamorphosed or altered, by heat from the earth's molten interior, or from contact with igneous or volcanic rocks, with their accompanying hot waters. Or, again, these deposits have been affected by hot or cold waters percolating through them, bearing materials which chemically act upon them; or, again, they may have been subjected to greater or less squeezing and pressure during the formation of the numerous wrinkles that old Mother Earth now wears upon her rugged face, deeply furrowed by her tears.

Of all the agents of consolidation and change in rocks, the chemically active waters are, to my mind, the most potent; and it appears to me probable that dry heat and pressure alone would be unable to produce any general and wide-spread rock alteration if it were not for the intervention of the percolating waters found in all rocks, so far as man has been able to penetrate the earth. These waters convey the heat and other chemically active agencies to the places where they can act. Metamorphosed or altered detritus forms the oldest known rocks of the Lake Superior district; and we know of the original rocks only by the remains of that *débris* now found in them. From the character of that *débris* it appears that here the original rocks were of igneous or volcanic origin; that is, they made up the early-formed crust of the earth, or else were produced by the earth's primitive volcanic activity.

When the muds, sands or shingle have been consolidated, they are found to form rocks that differ not only in the fineness of the material in them, and in their chemical and mineral composition, but also according to the different agencies and conditions to which they have been subjected.

Thus it is that the muds have formed the rocks known as the argillites, shales, most schists, and some gneisses; the sands have formed sandstones, quartzites, some schists, and most gneisses; while the shingle generally finds its expression in the conglomerates.

The term argillite is used to indicate those consolidated muds that were largely composed of clay or argillaceous material; but the argillites are commonly known as slates—a term properly applied to an argillite only when it has been subjected to pressure and chemical action to such an extent that it has the property of splitting indefinitely into thin plates that have no relation to the original structural or sedimentary planes of the rock. This property of being cleaved or split is known as cleavage, and it is by no means confined to that variety of argillite known as slate.

When quartz sands form a sandstone which subsequently has been greatly altered or indurated, so that the rock is composed of a very hard, compact mass of quartz grains, this variety of sandstone is known as quartzite.

The terms schist and gneiss are used to designate all those altered or metamorphosed detrital deposits whose minerals are arranged in more or less parallel bands, along which the minerals tend to lie flatwise or lengthwise, causing the rock to split into more or less regular plates parallel to these bands. These bands (or foliation of the rock) may or may not be coincident with the original planes or lines along which the detritus was deposited (planes of sedimentation), and in the majority of cases in the Lake Superior region do not so coincide. A striking example of this can be seen in the schist north of Teal Lake, where the planes of deposition run approximately northeast and southwest, while the foliation runs east and west.

The varieties of schist are named according to some one or more of the prominent minerals in them, as hornblende-schist, mica-schist, quartz-schist, chlorite-schist, actinolite-schist, etc., for the schists that contain the minerals hornblende, mica, quartz, chlorite, actinolite, etc.

The altered muds, sands or shingles may be found continuous over large areas; or they may be found, like their modern representatives, to pass gradually or abruptly into one another. Thus it is, that a quartzite is found to pass into quartz-, mica- and chlorite-schists; chlorite-schist into argillite-, conglomerate- and hornblende-schists, etc.

Eruptive, Volcanic or Igneous Rocks.

To obtain a fair idea of rocks of this character it is necessary to do as we have done with the detrital or fragmental rocks; that is, to observe carefully the recent forms and trace out their structure and various modifications and alterations. If this is done, we see that the eruptive rocks are changed or metamorphosed not less, and often more, than the sedimentary formations.

This may be illustrated by allowing some of the molten iron from our furnaces to run at waste over the ground and into the crevices, so as to be left exposed to the air, frost, wind and snow. It would first solidify, then crack or form joints, as all rocks do, and, owing to the action of the air and rain, it would decompose and alter until finally it would form an earthy iron-ore totally unlike the original iron. Why is this? The answer is that the iron, when it passes from its furnace, is exposed in the outside atmosphere to conditions entirely unlike those in the furnace, and it must change its state to conform with those changed conditions. So, too, the eruptive rocks, coming in a liquid state from the interior of the earth's furnace, cannot endure unchanged the conditions which exist at or near the earth's surface. They are in an unstable condition, and must be made over into a more stable mineral composition. The agencies that produce that change appear in general to be the same as those which alter the sedimentary formations, namely, percolating waters chemically active, pressure, and heat or cold. The first stage is the change from a liquid or pasty mass into a solid one; later there comes a more or less variable alteration that extends throughout the entire mass, and causes variation in the mineral composition and structure—so much so that at times no trace of its original condition remains, unless it be its form or its relative position to other rocks.

It is in consequence of these changes that rocks which were originally peridotites or olivine rocks are now called serpentines, actinolite-schists, talc-schists, dolomites and *verde-antiques;* and that formerly molten basalts are now designated melaphyrs, diabases, gabbros, diorites, eclogites, amphibolites, hornblende-schists, chlorite-schists, mica-schists, amygdaloids, traps, greenstones, variolites, granites, etc. It may here be said that schists result from the alteration of eruptive rocks, as well as by the change of sedimentary ones. It is alteration that causes rocks that were formerly andesites to be named phonolites, propylites, hornblende-porphyries, porphyrites, diabases, melaphyrs, diorites, granites, schists, etc. In the same way what were once trachytes now form felsites, phonolites, porphyries, granites, gneisses, etc.; while the rhyolites, in their alteration, form rocks called felsites, petrosilex, gneisses, granites, quartz-porphyries, etc. It will be inferred from the above that the alteration of eruptive rocks produces, from forms that were originally distinct, forms that are now known by the same name; while, on the other hand, the varieties due to the various changes of a single rock-species are very numerous.*

* See *Bull. Mus. Comp. Zool.*, 1878, V. pp. 39, 40, 275–287; 1880, VII., 1–164, 183–187, 351–565; *Proc. Bos. Soc. Nat. Hist.*, 1877, XIX., 217–237, 309–316; 1880, XXI., 91–103, 243–274, 288–291; 1883, XXII., 412–432, 485–489; 1884, XXIII., 197–211; *Mem. Mus. Comp. Zool.*, 1884, XI., 208 pp.; *Am. Jour. Sci.*, 1884 (3) XVIII., 94–104; *Science*, 1883, I., 127-130, 541; 1884, III., 486, 487; IV, 111; *Bull. Minn. Geol. Survey*, No. 2, 159 pp.; *Report of State Board of Geol. Sur.*, Mich., 1893, 196 pp.

The structure of eruptive rocks differs very much according to their composition, and according to the conditions under which they have cooled, whether slowly or rapidly, as well as according to the conditions to which they have been subjected. That is, a mass slowly cooling will be found to contain much larger mineral forms, known as crystals, than a mass suddenly chilled.

The eruptive rocks, in their relations to their associated country-rocks, will also vary according to the conditions in which they have reached their present position relative to the latter.

If the liquid material (lava) forces its way through a rock, filling the cracks that then existed in it, like putty filling a crack in glass, the solidified lava is known as a dike. It is to be observed, however, that when rocks are but little consolidated, the eruptive or liquid material tends to force itself along the planes of deposition of the sediments, or parallel with the foliation, or else to break irregularly through whatever portion of the rocks offers the least resistance. But when the rocks have become solid then the flow more commonly takes place along cracks or fissures in the rocks, which extend across the country, like the cracks made in a thin sheet of ice. Usually these dikes may be distinguished by their being closely welded on each side to the country-rock, which is often indurated or hardened at the point of contact; by their being compact and fine-grained at the junction with the country-rock, thus showing a rapid cooling, due to their coming in contact with the cold sides of the fissure; also by their being more coarsely crystalline or coarse-grained toward the center than at the margin, because of the greater length of time the interior mass would occupy in cooling; oftentimes by the dikes holding, on both sides, fragments of the country-rock caught up in the passage of the lava. The difference between the sides and the interior of dikes is usually less marked in those rocks which contain over 65 or 70 per cent. of silica than it is in rocks containing a less amount. Oftentimes the lava welling up through a fissure will fail to reach the surface, and usually hardens in a wedge or knob-like form; but at other times it flows out over the surface of the earth, in like manner as water passing through a fissure will flow over the surface of ice.

When lava flows out from long fissures and floods the country, such flows are commonly known as fissure or massive eruptions, especially if the flows were attended with little or no exl plosive action. If the lava passed through a hole or channe-like a "blow hole" in ice, and especially if attended with explosive action, it is commonly called volcanic. The massive fissure or quiet eruptions were more common in the earlier days of this earth; the explosive or volcanic eruptions have been more common in later geological time, or recent times. Since all these are manifestations of the same general cause, we shall use the term volcanic to include all eruptive phenomena.

Lava-flows may generally be distinguished from dikes or intrusive masses of lava by the underside of the flow being welded to the country-rock, by its having baked or indurated the underlying rock, and by its holding fragments thereof; also by its conformity to the original surface of that underlying country-rock. The flow is usually fine-grained or compact at its base, owing to rapid cooling; but a short distance from its base it presents a coarser texture, and usually shows the coarsest structure below the center of the flow, at a point which was the longest in cooling. The upper surface of the flow is commonly wrinkled, cellular and slaggy, if it has not been worn off. The overlying country-rock is laid down upon this surface; it conforms to the inequalities of the underlying lava, and generally contains fragments derived from it. The overlying sedimentary rock is not welded to the underlying lava, nor does one affect the other in any way, unless it be by chemical action.

When any explosive action has taken place, ashes and larger fragments of the disrupted lava are strewn about, which may or may not be subsequently worked over by wind and water. Lava, as soon as it is exposed to the waves, is worn away, like any other rock, and we find its worn detritus deposited by its side, ere the main mass has been cooled.

Chemically Deposited Materials.

Every kind of chemical deposit, even sublimation-deposits, can be considered as resulting from the solution of mineral matter through the agency of the chemically active percolating or surrounding waters, which remove substances from one locality to another, or replace one material by another. While it is not always true, it is a general rule that ore-deposits are most commonly found in regions of eruptive rocks, either ancient or modern, as in connection with such rocks the percolating waters are apt to be warmest and most highly charged with chemically active solvents.

The history of ore-deposits seems to be the result of a *universal law* which affects all rocks of the globe, and may be considered as the one which governs the entire universe, physical, mental and moral.

For the physical universe this can be best formulated, perhaps, as the *degradation and dissipation of energy: the passage from an unstable condition towards a more stable one: the tendency of all things to harmonize with their environment, that is with their surroundings, or with the conditions to which they are exposed.*

This appears to be the law under which the universe has moved from its beginning, and under which it will continue its course uniformly towards the end; no turning back can occur, and no energy once lost can be restored, except by the same Almighty Power which gave it birth.*

Without entering at all upon the question of the source of those rocks which have come from below the earth's surface and are known as eruptives, and which form a large portion of the so-called metamorphic series, it is sufficient for the present purpose to state again that, when they reach the exterior of the earth, their condition is one not adapted to the circumstances in which they are hereafter to exist. For a time, at least, prior to their eruption, they have been under far different conditions from the atmospheric ones on the earth's surface: of necessity, after their extrusion, there will be a constant tendency on their part to conform to these changed conditions. This is manifested most conspicuously in their loss of heat, and in their passage from a liquid to a solid condition. When solid, these rocks may be said to be in an unstable condition, in respect to their temperature, and also to the chemical combinations formed on solidification. Their chemical arrangements, as manifested in their constituent glass and minerals, are such as to necessitate a transference to a condition in which they will be less acted upon by the agencies to which they are exposed

* *Science*, 1883, I., 541; *Lithological Studies*, 1884, p. 1.

on the earth's surface, and this leads to degradation, dissipation and loss of energy on their part. In other words, the rocks tend to pass from an unstable towards a more stable state. The rapidity of these changes depends not only upon the chemical constitution of the rocks, but also upon the special circumstances in which they are placed. In the basic rocks, or those containing much iron, magnesium, calcium, aluminum, etc., the alterations are comparatively rapid, but in the acidic rocks much slower. If rocks of eruptive origin are studied under the microscope, these alterations can be readily traced from their earliest to their latest stages, and are usually found to be in a ratio to the ages of the rocks or to the particular influences to which they have been respectively subjected.

It is these alterations that have led to the multiplicity of rock-names, and to the confusion of nomenclature; lithologists and geologists, as a rule, formerly supposing that as a rock then was, so it always had been and always would be. For example, the lava-flows of Keweenaw Point, which were once identical with the modern basaltic lavas of Mt. Etna and of Kilauea, are now designated, on account of their alteration and age, as melaphyrs, diabases, diorites, etc.; andesite in its changed guise is designated as propylite, diabase-porphyrite, porphyrite, diorite, etc.; rhyolite as felsite, quartz-porphyry, petrosilex, orthofelsite, etc.; peridotites, or olivine rocks, as serpentine, talc-schist, etc.

The propylite of the Comstock Lode, Nevada, is a striking example. The present writer was the first to call attention to the fact that the fortieth parallel propylites were altered forms of pre-tertiary and tertiary andesites.* The position then taken has been fully confirmed by Dr. G. F. Becker,† and by his colleague, Arnold Hague. Dr. Becker further states that every decomposed rock in the district has been taken for propylite.

The above mentioned changes, or alterations, in rocks of the same composition appear to be largely dependent upon the action of infiltrating waters, and their rapidity seems in a ratio to the temperature of the waters or to the solvents contained therein. These alterations appear to consist, in general, of molecular transferences or chemical reactions in the rock-mass

* *Bull. Mus. Comp. Zool.*, 1879, vol. v., pp. 281, 285, 286.

† "Geology of the Comstock Lode and Washoe Districts," 1882, pp. 12–150.

as a whole, and are not confined to special minerals; hence has resulted the failure of theories of mineral pseudomorphism to explain rock-metamorphism, or alteration—the pseudomorphic changes in the rock mass being but the resulting accident of the greater and more general metamorphosis. In the process of alteration the original glass of the rock is broken up, forming various minerals according to its composition, while the original crystallized minerals are changed to a greater or less degree, the resulting minerals being quartz, various ores, anhydrous and hydrous silicates, carbonates, etc. In the course of these changes there is everywhere seen a tendency to localize these secondary products, especially the ores, which results in the removal of material of one kind and the deposition of another in its place, or in the filling of fissures and cavities in the rocks. It is not uncommon to find in rocks minute veins that under the microscope show variation in their filling as they pass through different minerals. What has now been described as taking place in one rock takes place in all, and frequently with various interchanges and reactions between the different associated rocks. If we pass gradually from alterations seen in the rock, and from the minute fissures observed under the microscope, to deposits visible to the unaided eye, to joint- or fissure-planes that traverse large masses of rock, or to cavities, or to any condition of rock structure that will admit the chemical deposition of mineral matter, then, whether we have ore-deposits or not seems to depend upon the activity of the alteration and upon the amount and kind of matter brought together. It is well known that valuable ore-deposits are more apt to occur in regions of eruptive and altered rocks than elsewhere.

From what has been said above of the general alteration of rock-masses and the partial localization of their contained mineral matter by percolating waters, it would appear that this cause gives rise to all chemical deposits, even to sublimations, when the water is vaporized.

Instead of the re-deposition of the mineral matter, taken up by the percolating waters, in the rock or in contiguous cavities, it may be borne far away, appearing in spring-, river-, lake-, and ocean-waters, and in deposits laid down by them; precipitation taking place wherever the proper conditions exist.

Of all theories that have been proposed to account for ore-deposits, there are few that are not correct for some form of ore-deposits in certain localities. While the practical use of these theories is to aid us in understanding the nature of the deposits, as a guide to their exploitation, the difficulty in such a use lies in the abuse of the theories through their indiscriminate application to all deposits. Our rule ought to be to study every deposit thoroughly, and after the study, not before, apply that theory which best answers to the observed conditions, since all theories ought to be generalizations or expositions of observed facts, with a prophecy for the future.

It is not doubted here that all ore-deposits not of a mechanical or eruptive origin can be attributed to the general alteration and change in rocks that result from the general dissipation and degradation of the potential energy of the constituents of the earth's crust, in the universal passage of matter from an active towards a passive and inert condition.

This general alteration manifests itself in a universal chemical or molecular transference—a transference of material, leading to the segregation or localization of the ores in the places in which they are now found; it manifests itself in the deposition of mineral matter in the veins and cavities of the rocks themselves, in deposits from springs, in bogs, lakes, etc. From this it would follow that all ore-deposits not eruptive are, as regards the earth, superficial phenomena and dependent on its external agencies, although they may be deep enough so far as man is concerned.

Again, few of these ore-deposits would be expected, except in regions in which percolating waters and their attendant metamorphism have been efficient agents;* while the various forms of ore-deposits would be associated with, and grade into, one another.

If we start, as all geologists do, with the belief in an originally hot fluid globe, all rocks must have been derived, primarily, from fluid material, which contained all the elements of the metals or ores. The detrital rocks would naturally partake of the metalliferous character of the rocks from which their material came, and each would develop similar changes; while in

* Whitney, *Contributions to American Geology*, 1880, vol. i. "The Auriferous Gravels of the Sierra Nevada of California," pp. 310, 331, 350, 356.

the chemically and organically formed rocks, in accordance with their special conditions of formation, there can readily be suggested agencies for the precipitation of useful ores throughout their mass during the time of their formation, the precipitated ores being gathered up subsequently in all those rocks by the percolating waters.

In order to estimate the value of deductions regarding the source of the ore in an ore-deposit, based on the analysis of the minerals in the adjacent country-rock, it is necessary to look into the question of the origin of these minerals. If the consolidation of rocks be taken as a reference-point, the minerals they contain naturally fall into three classes:

(1) Those of prior origin—foreign.

(2) Those produced by solidification (crystallization)—indigenous.

(3) Those produced later by alterations in the rock-mass, or by infiltration—alteration, or secondary.*

The first can conveniently be separated into two divisions:

(*a*) The minerals that are characteristic of the rock, whatever may be its locality or age.

(*b*) Those that are accidental, as, for instance, fragments caught up during the passage through or over another rock.

Any rock may contain all three classes, or only one or two, as the case may be. A few minerals may be cited in illustration. Olivine in the peridotites is an indigenous mineral, but in the basalts it is foreign, although generally characteristic of them. Serpentine, when not an infiltration- or veinstone-product, is always a secondary, or alteration-product. Hornblende in the recent andesites is foreign, but in the older andesites, and in almost all the older rocks of every kind, it is either a secondary product or is a more or less altered mineral. The micas, feldspars and quartz occur as foreign, indigenous and secondary products. As a rule, quartz is foreign in the modern rhyolites; but in the older rocks of this type, felsites and quartz-porphyries, it is both foreign and secondary. All hydrous oxides and silicates and all carbonates appear to be alteration-products.

Generally, the different modes of occurrence of these min-

* *Bull. Mus. Comp. Zool.*, 1879, V. 277, 278; *Lithological Studies*, 1884, pp. 25–29.

erals can be readily distinguished from one another under the microscope by the characters of the minerals and their relations to the rock-mass.

Further, it may be pointed out that olivine, except in the more recent rocks, is found, as a rule, to be more or less altered to, or replaced by, serpentine, quartz, iron-ore, carbonates, etc.; augite by hornblende, biotite, chlorite, etc., and feldspar by quartz, kaolin, micaceous and chloritic minerals, etc.

These changes are so common that it is rare to find in the older rocks original minerals that remain unchanged.

Again, almost every mineral in rocks is found to contain inclusions of other minerals, of glass, liquid and gases, thus vitiating conclusions drawn from chemical analysis of the mineral.

Since ore-deposits are, in general, associated with altered or metamorphosed rocks, and occur in regions in which thermal waters have been active, the country-rock would naturally be more or less changed, and sometimes completely decomposed. In the process of the formation of the ore-deposit it may happen that the ore-material will be entirely removed from the adjacent rock, or in this rock there may be deposited ores that never existed in it before, the ore-material having been brought from a distance by the percolating waters.

From the above it follows that chemical analyses alone, either of the country-rock or of its enclosed minerals, lead to unreliable conclusions as to the source of the ores, as they indicate only what now is in the rocks or minerals, and not what might originally have been there. Hence it is an unphilosophical procedure to build any general theory upon such analyses, unless they are carefully supplemented by thorough and accurate geological study of the region in question.

If, by chemical analysis, any accurate deductions are to be drawn regarding the original source of the ores, it seems necessary that we should select those rocks and minerals that are known to be fresh, unaltered and free from any foreign inclusions that would influence the result. Such materials could only be obtained from recent lava-flows, recently-formed limestones, etc.; for no rock that has been exposed for a considerable length of time to the earth's meteoric agencies can, in the writer's opinion, be said to be in its pristine condition. Most analyses of such rocks fail to include tests for sufficiently minute quantities of such materials as comprise the more valuable ore-deposits to permit, as yet, any general conclusion to be drawn concerning the source of all our metals. The nearest approach to any such analyses is in the meteorites, which are unaltered, and which in composition and structure are closely allied to certain classes of terrestrial basic rocks. These meteorites are found to contain copper, tin, nickel, cobalt, arsenic, zinc, manganese, chromium and graphite, and it is probable that more careful and searching analyses would reveal in them and in the lavas other and more precious metals.

While it would appear probable that the elements of the useful ores were often originally disseminated through the rocks, particularly the eruptive ones with which they are associated, and were subsequently concentrated by the agency of percolating waters, proofs that this theory is correct are yet wanting—the theory resting mainly upon the observed structure of the ore-deposits, their association and the alteration of the adjacent rocks, or, rather, upon the geological conditions observed, than upon any chemical analyses yet made.

To summarize, it may be said that there is no known rock, unless a partial exception be made for rocks in the form of glass, that will not absorb water to a greater or less extent. All these waters are chemically active, whether hot or cold, pure or impure; but it is undisputed that heat, pressure and substances in solution in these waters greatly increase their chemical activity. It has been pointed out that all rocks are modified or changed through the action of the chemically active waters, leading either to the decomposition of the rocks or to a change in their mineralogical composition, and often to a change in structure. It has further been pointed out that the alteration brought about by chemical waters, with or without heat and pressure, has caused rocks formerly of the same character and composition to take upon themselves very diverse forms. It has also been noticed that rocks of entirely different origin and structure, like sedimentary and eruptive rocks, have been so changed by this action that the resulting forms are indistinguishable from one another except by their geological mode of occurrence.

All these changes in rocks have not proceeded without certain mineral matters being removed from one locality and deposited in another. A strong tendency is observed towards a localization of the moved mineral product or towards special aggregation of mineral matters, some of which are economically of no importance, while others form useful ore-deposits.

One of the latest phases of the formation of deposits of value has been the filling in of fissures by the water-deposited quartz and other vein-materials, or, in case no crack nor fissure existed, by the removal of the country-rocks along certain lines and their replacement by vein-matter.

Veins thus formed may contain only quartz or other valueless minerals (gangue), or they may hold valuable metals and ores. It is in veins that the gold and silver north of Ishpeming are worked, the veins at the Ropes gold-mine being in serpentine, while the others are in diorite, granite, felsite and schist.

Potsdam Sandstone.

The rocks of the Azoic system were still subject to the same denudation by frost and rain, and by the beating of the waves after that formation had been completed, that the different members of the formation had been subjected to before the entire system was complete. That is, there were deposited about the Azoic rocks mud, sand and shingle, in like manner as such materials are being deposited on our lake-shores at the present time. This detritus, on consolidation, has formed a series of shales, sandstones and conglomerates, which overlie or abut against the Azoic rocks, and are mainly composed of the *débris* of the latter. These sandstones form in Michigan the base of a new system of rocks which is generally considered to be the equivalent of the Potsdam sandstone; hence the rocks are provisionally said to be Potsdam.

South of Carp river this sandstone can be seen lying against the Azoic quartzites and formed out of their *débris*. The Marquette sandstone quarries are in this Potsdam sandstone, and at the base of the quarries may be found conglomerates made up of the underlying Azoic quartzites, diorites, argillites, schists, etc. A short distance south of Hotel Marquette there can be seen, on the west side of Champion street, leading to South Marquette, some rounded diorite- and schist-knobs that have been polished and grooved by former glacial action. These knobs have been exposed by excavations made for the purpose of obtaining filling for some adjacent ravines. A matter of special interest is the finding of small veins of the formerly overlying Potsdam sandstone that has filled the cracks in these rocks, which formed bosses or little knobs on the shores of the old Potsdam sea. The Potsdam sandstone is found overlying much of the serpentine of Presque Isle where the basement conglomerate is well exposed, although that conglomerate has subsequently been much altered, apparently, by heat and water. The same sandstone occurs further north on the shore, and on some of the islands that overlie the Azoic granite, which has been decomposed for some distance below the base of the sandstone. This decomposition is seen to extend to the boulders of granite and other rocks in the basement sandstone and conglomerate. These changes unquestionably have occurred since the sandstone was deposited, and the percolating waters are apparently the cause of the decomposition. The sandstone extends, with greater or less continuity, along the shores of Lake Superior, around Keweenaw Bay and Keweenaw Point, where it was first designated by the present writer as the Eastern sandstone. On Partridge Island clayey or sandstone fragments occur abundantly in the Potsdam sandstone itself. The writer has seen similar deposits in the process of forming on the Bay of Fundy, in the vicinity of St. John.

The Potsdam sandstone was evidently formed on the shores of a body of water accessible to ocean-tides, as it shows ripple-marks, sun-cracks, rain-drop impressions and mud-flows, which indicate conditions that are only known to exist in localities where the alternate ebb and flow of the tides occur.

The age of part of the Eastern sandstone of Keweenaw Point has been proven to be at least Lower Silurian (Ordovician) or Cambrian and probably Potsdam, by the work of Mr. W. L. Honnold.* A limestone west of L'Anse in T. 51, R. 35, has been described in Jackson's Report (1849, pp. 399, 452), Foster and Whitney's Report (Part I., 1850, pp. 117–119), and in Rominger's Report (1873, I., part 3, pp. 69–71), and the limestone has been considered, from its fossils, to be of the Trenton or some adjacent lower strata. It was inferred by Jackson that the limestone underlies the sandstone, but by other observers that it overlies it, although no direct contact was seen.

* *Am. Jour. Sci.*, 1891 (3) xlii., 417–419.

Excavations made by Mr. Honnold's party and reported by him have exposed the contact of the two formations, and show that the two form a synclinal or oblong basin-shaped fold, with the limestone overlying and in direct contact with the sandstone. The existence of this fold in the sandstone, as well as in the limestone, removes the difficulty previous observers have had in reconciling the obviously tilted limestone with the supposed horizontal sandstone, and proves that the Eastern sandstone exposed here is of Lower Silurian (Ordovician) or Cambrian age, and older than this limestone.

At the point of contact of the two formations, exposed by excavation, the sandstone and limestone appear to be conformable, and they are seen constantly to agree in dip and strike. The contact between the two formations is abrupt, without any beds of passage, although the upper layers of the sandstone contain considerable carbonate of lime and magnesia, and the lower layers of the limestone much silica.

These observations are considered to be confirmatory of the commonly received view of the Potsdam age of the Eastern sandstone; while the contorted state of the sandstone which extends at least a mile and a half west from the limestone locality may have weight in deciding the relative age of the Eastern sandstone and the copper-bearing rocks.

During the time of the deposition of the Eastern sandstone (Cambrian), or previous to it (Algonkian), volcanic activity again commenced, and the central portion of Keweenaw Point is found to be composed of alternating lava-flows, sandstones and conglomerates, deposited upon the tide-washed sinking shores of the sea. The intermittent volcanic activity ceased for a while after the main range of Keweenaw Point was produced, leaving time for the formation of a broad belt of sandstone and conglomerate; but it again recommenced, making the basaltic rocks exposed along the northern side of Keweenaw Point at Eagle Harbor, Agate Harbor, Copper Harbor and elsewhere.

In connection with these lava-flows from fissure eruptions, which were of a basaltic character, there was also extravasated much volcanic material of a trachytic and rhyolitic nature, the *débris* of which makes up the chief portion of the interbedded sandstones and conglomerates. These occur in the form of intrusive dikes, bosses, etc.

The basaltic rocks forming the southeastern range of Keweenaw Point, known as the Bohemian Mountains, were considered by Foster and Whitney to be intrusive masses erupted subsequently to the formation of the main deposits in this region. Irving, however, considered them to be ordinary flows, like the rest of the lava-flows of Keweenaw Point. He does not advance any special proof of this proposition, while the phenomena presented by him, as well as by Foster and Whitney, appear to be more in accordance with the view that they are later eruptive masses, as held by the last-named observers. However, the question is yet an open one. The basaltic lava-flows are known to be such, as pointed out by Foster and Whitney, and later by Marvine and Wadsworth, by their baking, or indurating, or hardening the underlying rock; by their sending dikes and tongues down into the rocks; by their having caught up fragments of the underlying rock; by their crystalline structure being best developed below the center of the flow; by their having no effect upon the overlying conglomerate, while the *débris* of the lava is to be found in the base of the conglomerate; by the overlying conglomerate and sandstone filling cracks or forming clasolites* in the underlying lava-flow, etc. The thinner basaltic lava-flows were cooled quickly, so that they contained much glass, which was readily decomposed by the percolating waters. In their altered condition they now form rocks known to geologists as melaphyrs, but which from their present structure are locally called amygdaloids.

The thicker flows formed heavy beds, which cooled more slowly, became more crystalline and were less easily affected by the percolating waters than the thinner flows. These heavy flows, owing to their alteration, now form rocks which by geologists are named diabases and gabbros, but locally called traps and greenstones. All of these melaphyrs, diabases and gabbros were once lavas of the same chemical constitution, differing only in structure and in those differences of crystallization and mineral constitution that result from slow or rapid cooling.

* See *Report of State Board of Geol. Sur.*, Michigan, 1893, pp. 129, 130, 147, where the present writer defines a clasolite as a sedimentary deposit of mineral matter of indefinite length and depth, and comparatively small thickness, differing in character from, and posterior in formation to, the rocks which inclose it, *i.e.*, the so called sandstone dikes of Diller and others.

These flows must have taken place over the gently sloping tide-washed shore of the sea, which shore was gradually, or it may be at times abruptly, sinking, so that the flows and their detrital deposits accumulated at about the same rate as the shore sank, making the shore-line approximately constant. This must have been the case, or the lava-flows and conglomerates would have been more irregular and less constant: they would have covered a more limited area, and would soon have been built up beyond the reach of the waves.

Owing to the natural irregularities of a lava-flow, and the resulting inequality of the sedimentary deposits, it is to be expected that some inequalities in thickness of both formations should exist, and that sometimes one or the other should be wanting. For instance, if a portion of the lava was raised above the sea, that portion would not be covered by either sandstone or conglomerate, but only by its own decomposition products, if even they were not carried away by the rain. Hence it happens that the interval between two flows is marked at one point by a conglomerate, but elsewhere only by a thin seam; or, as is often the case, the two flows are interfused.

It also frequently happened that a comparatively short time existed between two flows. In such a case little or no conglomerate could form between them, and as the latter flow fused again the top of the earlier flow, the two became united into one mass, so that it is difficult to ascertain where one begins and the other ends.

The Copper-Bearing or Keweenawan Series.

The relation of the lava-flows with their interbedded conglomerates to the Eastern sandstone is a matter of great scientific and economic interest, and has given rise to much discussion, which is likely to continue for many years to come, until the whole truth shall be known. In the report of Foster and Whitney, the Eastern sandstone was considered to have been once continuous with the Western sandstone* of Keweenaw

* These designations for these sandstones were first used by the present writer and later adopted by Irving. *Notes on the Geology of the Iron and Copper Districts of Lake Superior*, 1880, pp. 98, 107, 108, 110, 116, 121, 122; *Proc. Am. Assoc. Adv. Sci.*, 1880, xxix., p. 129; *Proc. Bost. Soc. Nat. Hist.*, 1880, xxi., pp. 92, 94, 103. "Correlation Papers. Cambrian." *Bull. U. S. Geol. Sur.*, No. 81, 1891, pp. 252, 335.

Point, but it was thought that the two parts had been separated by a fracture or fault-plane that extended along the entire southern side of Keweenaw Point. This fault allowed the sandstone on the east to remain horizontal, while the lava-flows on the west were tilted up at their present angle, and the overlying western sandstone was subsequently worn away. The sandstone east of the fault-line was said to lie horizontally, or to dip to the southeast.

Later, attention was called to certain observations made along the line of the fault, especially at the Douglas Houghton Falls. These observations caused the lava-flows and their interbedded sedimentary rocks to be considered as an older geological formation than the Eastern sandstone. It was said that the lavas formed an old sea-shore bluff on the Potsdam sea, and that the sandstone was laid down horizontally, abutted against the cliffs, and was formed from their water-worn *débris*. Various other opinions have also been advanced, reference to which our limited space does not permit.

In 1879 the present writer made an examination of the formations at the points at which, on the Douglas Houghton and Hungarian rivers, the Eastern sandstone comes in contact with the lavas, or, as they are now commonly called, the copper-bearing rocks or Keweenawan series. He found that the sandstone, instead of lying horizontally, dipped gradually or irregularly toward the northwest; and that, instead of abutting against the copper-bearing rocks, it was overlain by the latter, and the two were interbedded. Later, the correctness of these observations was denied by Irving, who upheld the view of the greater age of the copper-bearing rocks, but moved the supposed sea-shore cliff from its former supposed locality and placed it elsewhere. Subsequently the question was taken up by Irving and Chamberlin in defence of the view that the copper-bearing rocks are older than the Eastern sandstone. But upon studying their published observations, together with their sections given in this later work, it will be seen that their preceding observations are discredited, and that they fully sustain the correctness of the present writer's statement that the sandstone dips under the copper-bearing rocks, instead of being separated from them by a vertical fault or an old sea-bluff. The result is that in the main point at issue the present writer was shown to be correct, *i.e.*, that the sandstone does underlie the copper-bearing rocks, and then the main question was transferred to one of interpretation of the observations. Do the lavas overlie the Eastern sandstone on account of their having flowed over it in the form of a molten lava, as the writer then claimed, or had the lavas been thrust up over the sandstones through the motion of an older solid mass along an oblique fault-plane, as last held by Irving and Chamberlin?

During the summer of 1889 an examination of this question was made by the Michigan Geological Survey, then under the writer's direction, and the rocks were uncovered along the line of contact of the sandstone and lavas for the purpose of ascertaining their exact relations. The result has been to prove to the present writer, beyond any reasonable doubt, that on the Douglas Houghton and Hungarian rivers, as well as on Sec. 20, T. 56, R. 32 N., the sandstone does dip gently toward the lavas, and finally passes under them with an increasing dip; that the junction is not a fault-junction but that of a lava-flow upon an underlying soft sand and mud. The lowest bed of melaphyr was found on the Douglas Houghton river to be overlain by sandstone, as described by the writer in 1880, although this fact had been denied by the before-mentioned authors. The copper-bearing rocks on the north side of Douglas Houghton river are seen to overlie the Eastern sandstone for about 150 feet. Along the line of contact to the north on the St. Louis location and in Wall ravine, as well as south of Portage Lake, proof of distinct faulting could be obtained, which sustains the fault claimed by Foster and Whitney, Irving and others. Along the Douglas Houghton contact, no signs of any fault, or but few signs, were found; but in the copper-bearing series, just below the falls, several fractures, with evidences of the motions of sides, were observed, that would indicate a faulting here.

The fault-plane, wherever observed along the line of contact, showed that the hanging-wall was on the side next the copper-bearing rocks. It is well known by all miners and geologists that in all normal faults, *i.e.*, the commonly occurring faults, the rock on the hanging side of the fault has slipped down relatively to the rock forming the foot-wall. A reversed fault is one in which the hanging-wall side has been pushed up on the foot-wall side of the fault. The reversed faults are generally considered to be rare; so much so that some geologists deny that they ever occur, although the present writer has seen them associated with normal faults in the Cheever ore-bed at Port Henry, New York. This rare mode of faulting is the one assumed by Irving, who was obliged also to assume that the uplift of the hanging-wall was accompanied by a thrust to the eastward: a view that some observations by the Michigan Geological Survey, especially by Professor A. E. Seaman, would sustain; but these, the present writer thinks, need more careful examination and further confirmation before they can be accepted as conclusive, since all the observed facts can be explained by the repeated movements that usually occur along the sides of a fault.

The present writer holds that the sandstone underlies the copper-bearing rocks, and that the first lava of that series flowed over the Eastern sandstone, which is older than the copper-bearing or Keweenawan series. Subsequently a fault-line or fissure was formed, running near what is now the point of contact of the sandstone and lavas, sometimes exactly at that point, sometimes on the lava side, and probably sometimes on the sandstone side of it. Along this fi.sure it is probable that a normal fault occurred, along which, by the slipping down of the hanging or wedge-shaped side, the sandstones and their interbedded lavas were more or less bent downwards or contorted, as they are now found to be. This normal faulting accounts for the fact that sometimes the lava and sometimes its associated conglomerate is brought in contact with the Eastern sandstone along the fault-line. It is to be remembered that in almost all faults there is more or less rubbing back and forth, or up-and-down motion, although the final result of these varied motions is the production of a reversed or normal fault, according to the direction in which the greatest amount of motion took place.

This view would explain most of the difficulties that geologists have had in understanding this series, especially if it should be shown that the lava-flows came from the main lake-side instead of from the Keweenaw Bay side, as that would only require the cut-off remnants of the edges of the lava-flows to be removed by denudation on the Keweenaw Bay side.

Should the reversed fault be proved to be the true one, then the view of Foster and Whitney concerning the relations of the copper-bearing rocks would appear to be more correct than that of Irving, while a normal fault would be consistent with the theory of Houghton, Jackson and Marcou, that the copper-bearing rocks are of Triassic age.

Veins and Copper-Deposits.

Besides the fault before mentioned, numerous fissures cross Keweenaw Point instead of running longitudinally with it, and more or less faulting occurs along these fissure-lines. Portage Lake lies in a trough excavated along one of these fissures, while many of the others are filled with vein-matter, which has been mined to a greater or less extent. These fractures and fissures, with faulting across Keweenaw Point, probably were developed subsequently to the formation of the longitudinal fault or faults, if more than one such fault shall later be proved to exist. Should such be the case, it would account for part of the assumed thickness of the beds.

The before-mentioned fissures seem to have been formed by powerful movements of different parts of the rocks that caused the cross-fracture and dislocation of the latter. The movements were repeated from time to time, causing a rubbing, grinding, breaking and polishing of the parts adjacent to the fissures. After the main fissures had been formed, the subsequent movements would not cause any very extensive secondary breaking of the compact and heavy beds of diabase and conglomerate, but in the soft and scoriaceous melaphyrs the fracturing would be much greater, so that the parts adjacent to the fissures would be much broken. During the time of the fracturing, and subsequently, these fissures served as channels for the chemically active waters, which also percolated through the adjacent rocks. In the scoriaceous and easily decomposable melaphyrs the veins were widened by the decomposition of the adjacent rock, but in the coarsely crystalline and heavy diabases, as a rule, the same effects were produced either not at all or only to a limited extent. The sandstones and conglomerates, being composed principally of trachytic and rhyolitic material, are much less affected by percolating waters than the basaltic rocks; hence the fissures are not generally widened in them, especially if they are in thick beds. At the time when the percolating waters were acting on the rocks adjacent to the fissures, they were also working in the rocks everywhere upon Keweenaw Point.

In many localities the evidence is strong that the percolating waters were hot, while in others, as remarked by Marvine, no sign exists that they were above the temperature of the waters of the present day. These waters percolated with more or less readiness through the rocks, causing a greater or less alteration and decay, while the substances they took up were deposited in any fissures, cells or other open spaces that existed in the rock, or else portions of the rock were dissolved out and their places were refilled. This is strikingly seen in the conglomerates, like that of the Calumet and Hecla, in which pebbles of the easily-decomposable melaphyr have been partly or entirely removed and their places filled with copper or some other minerals.

Besides copper, the deposited minerals are mainly quartz, calcite, epidote, laumontite, prehnite, delessite, chlorite, datolite, analcite, orthoclase, apophyllite, etc. All, or nearly all, of the materials that fill the crevices, cells and other places in the lavas and conglomerates apparently were derived from the decomposition of the lavas themselves, and the course of the waters carrying these materials in solution seems to have been downward. The fissures that form the veins were filled at the same time and by the same agencies as those that acted upon the rocks, and the materials in them likewise appear to have been obtained from the adjacent rocks themselves. In the narrower portions the veins are often filled with the vein-matter proper, but in the wider portions the veins are often composed of broken-up masses of melaphyr, etc., cemented by vein-matter.

In the veins the copper is found intimately mixed with the gangue, or in sheets or irregular masses. In sheet-form the copper extends downward or has its sides approximately parallel with the vein. Often the sheet is divided, and holds between its parts some of the gangue or melaphyr. It is also not uncommon to find, entirely enclosed in the copper, masses of melaphyr, quartz, calcite or other vein-materials. The melaphyrs themselves are often impregnated with copper adjacent to the veins. Good illustrations of the veins can be seen at the Phœnix, Cliff, Central, Copper Falls and other mines in Keweenaw county.

In the vicinity of Hancock, Houghton and Opechee some of the old lavas are mined. As stated before, these old lava-flows, which now form melaphyrs (amygdaloids), have been greatly acted upon by water, and have had deposited in their mass different minerals associated with more or less copper. The copper is generally deposited in an irregular manner in the melaphyr, forming strings, globales, irregular masses, etc. These deposits are not in the form of veins, but are impregnations of old lava-flows, and hence are in the form of beds. As an example of mines worked upon these old lava-flows there may be cited the Quincy, Franklin, Osceola, Atlantic, Huron, and the Copper Falls in part. The Copper Falls has been worked in part on an old lava-flow of a very scoriaceous character that formed originally a black, rough, cellular lava-sheet covered with clinkers, similar to many well-known modern lava-flows. At the time of the flow, or after it, the interstices were filled with detrital mud, while the various parts of the flow appear to be connected, and do not form true water-worn pebbles. The writer has collected at Copper Falls portions of the rock that show the hardened exterior crust and the cellular interior, as they occur in small masses and bombs of modern lavas, while he has found preserved intact the original ropy, stringy, twisted surface of the lava. The Copper Falls bed, above described, is locally called the ash-bed, but it is a melaphyr or a true lava-flow, and not a bed of volcanic ashes. The Atlantic mine appears to be worked upon the same or a similar formation.

Besides the veins and lava-flows, the conglomerates have also been found in places to have had their interstices filled in with copper and other minerals. In them the old cementing mud, and oftentimes the pebbles of melaphyr, have been removed by percolating waters, and their places filled with copper, which penetrates even the minute cracks in the hard rhyolite (quartz-porphyry) pebbles. These old sea-beach conglomerates are now worked in the Calumet and Hecla, the Tamarack, the Allouez and other mines. There are thus mined in this region three distinct classes of deposits:

Copper-Deposits of Keweenaw Point.

1. Vein-deposits (fissure-veins).
2. Flow-deposits (melaphyrs or amygdaloids).
3. Bed-deposits (conglomerates).

The conglomerates are known to be old sea-beach deposits, like those that are forming along the lake or ocean at the present time. This is proved by the rounded and water-worn character of their pebbles and grains; by the observed water-action on the surface of the underlying lava-flow; and by the fact that at their base the conglomerates contain considerable basaltic mud and pebbles derived from the underlying lava, both of which diminish in amount or are entirely wanting as the distance from the underlying trap increases.

That the copper was deposited from water, with or without electro-chemical action, is shown by the fact of its being found inclosed entirely in minerals known to be formed by water only; also by its enclosing such minerals; by its being found in disconnected or isolated masses in the lavas and elsewhere, and by its greater abundance where there are to be seen the most signs of water-action. Had the copper been deposited by igneous agencies subsequently to the formation of the melaphyr and conglomerates it would have had a channel or line of passage, and would have been continuous along that line, so that all the different masses of copper would have been connected together downward, unless separated by fractures or faults.

The copper seems to have needed for its deposition the open spaces of veins and fissures, and rocks that were porous and cellular, or those whose parts were easily removed by the percolating waters, like melaphyrs or the cementing mud of the conglomerates. In truth, the copper seems to have been deposited wherever there were found any places in which to leave it.

From the fact that the copper is generally found most abundantly under the heavy lava-flows, and associated with minerals evidently the product of the decomposed lavas, it appears probable that the copper was once finely disseminated through the lavas, and has since been concentrated by waters percolating through them. This view is advocated by Müller, Bauermann, Marvine and myself, while a similar view has been advanced by S. F. Emmons to account for the origin and concentration of the Leadville ore-deposits.*

Had the copper been derived from the sandstones, then one would suppose that under them should be found the greatest supply of copper; but such is not the case. That the course of water depositing the copper was generally downward is indicated by the finding of spikes of copper and calcite that extend from one bed down into others, with the small end downward, like an icicle; by the fact that when the copper is not uniformly distributed throughout the bed or flow that is mined it is often, although not always, more abundant in its upper portion; and by the fact that the largest masses of copper have usually been found in the upper portions of the veins.

That the copper was deposited after the copper-bearing series was complete is shown by the fact that it is found in fissures extending across the beds that could only have been produced after the beds were in place; by the fact that the copper was deposited subsequently to the jointing of the lavas, owing to its now being found wrapped around the pieces formed by jointing; and by the extension of the copper from one flow down into another as a continuous mass.

The means by which the copper was concentrated and deposited as native copper, instead of occurring in the form of the usual copper ores, is an interesting and as yet unsolved problem that awaits the attention of the chemist who is willing to give his time and thought to the subject, although Pumpelly advocates the idea that the principal agent is the oxide of iron. In this he has much to sustain him, and his view is generally adopted.†

The structure of Keweenaw Point may, then, be summarized as follows: A deposit of sandstone overlain by lava-flows mingled with more or less of interbedded conglomerates, and finally overlain by sandstones. Subsequently these beds suffered longitudinal and cross-fracturing and faulting. Later all

* Müller, *Verhl. d. Natur. Gesell.*, Basel, 1854–57, pp. 411–438; Bauermann, *Quart. Jour. Geol. Soc.*, 1866, XII., 448–463; Wadsworth, *Notes on the Geology of the Iron and Copper Districts*, 1880, p. 126; Emmons, *Geology and Mining Industry of Leadville*, 1886, pp. 378, 379.

† *Geol. of Mich.*, 1873, I., part II, p. 44.

were acted upon by percolating waters, both hot and cold, by which the rocks were altered to a greater or less extent, and the copper was concentrated and stored up in the conglomerates, lavas and veins in which it is now found.

The above account gives in brief a general idea of the geology of the region touched upon here, as the writer interprets the facts observed. He is, however, aware that different interpretations of the same facts are made by others. He has therefore called special attention to the important differences of interpretation. In the copper-bearing rocks, the question of their relation to the Eastern sandstone is one of great economic interest in these days of diamond drills and deep shafts. One can readily see this when one considers that it involves the question, Do the copper-bearing rocks extend out under the Eastern sandstone or not? If they do, their exploration becomes merely a question of how great thickness of sandstone must be bored through. If they do not, then the question ought to be settled by the geologist, if possible, in order to save waste of money in unnecessary exploration on the part of those who are interested in mining.